[redacted] DOE b(3)

This seems to be true even for so-called "clean" devices - capture in the fuel is quite high. (Calculated neutron numbers and energies for six typical weapons are contained in LA-2246, Goad and Allen.) For detonations in air the neutrons are captured in nitrogen of the a ir; [redacted] DOE b(3) (Can. J. Physics, 1, 29, 1951.) The cross section is approximately 1/v and contained in BNL 325. The effect of the shock wave upon these neutrons is not well known; Monte Carlo calculations by Biggers of LASL indicate the bulk of the neutrons stay ahead of the shock wave. This would put the source of gamma rays ahead of the shock but probably quite close to it. (Some calculations are outlined in LA-1620 using the interior of the shock wave as the source.) For the high pressure ranges the shell source character may be quite pronounced as is indicated by the data. Following the explosion gamma ray peaks but preceding that, gamma radiation which is clearly due to capture in nitrogen, there is a region of gamma radiation [redacted] DOE b(3) whose origin is yet unknown. Radiation from isomeric states of fission products has been postulated and, though refuted by Bethe, has recently been observed at ORNL and LASL, though whether of the right magnitude remains to be seen. Another postulate is that it is due to neutron capture in nitrogen contained in the shock wave [redacted] DOE b(3). For larger yield explosions its contribution will be smaller compared to the total because of the shock wave enhancement of the latter gamma radiation.

The remaining radiation, appearing after the nitrogen capture component, is that due to fission product activity. The fission product gamma radiation time dependence is given by $3 \times 10^8 e^{-0.106 \ln^2 10.5}$ r/sec at 1 m per kiloton by Starner of LASL in a re-evaluation of some data of Fermi's group during the war. Its spectrum is also assumed to be the Motz spectrum. The fission fragments remain behind the shock wave and remain with the fireball. As the shock wave has the effect of piling the air within the shock radius in the region just behind the shock the $\int_0^{R_s} \rho\, dr$ shows a marked decrease even before arrival of the shock wave and a greater decrease following passage of the shock. The effect is greatest for high yield detonations and high overpressure regions. The enhancement for the few

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megaton region the overpressure range of interest can be three or four orders of magnitude. (An upper limit may be obtained by assuming all air is removed between source and point of interest.) The rise of the fireball containing the fission products makes the radiation fall off much faster than the $t^{-1.2}$ which Starner's relation becomes at times longer than 20 seconds.

To calculate the gamma radiation versus time for the fission product component particularly, it is necessary to determine $\int \rho \, dr$ versus time and the cloud height versus time. $\int \rho \, dr$ at LASL has been obtained from Fuchs M Problem and the cloud rise from EG+G data of which there is a large amount taken since 1953.

There are also available more recent data on fission product gamma radiation, e.g., Oak Ridge data, and on nitrogen capture data from Chalk River. These might be better than those quoted above.

I also suspect that the curves in TM-23-200 are derived through Liedke's (NDC), AFSWP 1100, calculations done under contract to AFSWP and has the above as a starting point. It would be worth exploring this possibility and if so try to determine the quality of the work and save some labor. These calculations appear to me to be well done but may lead to high predictions since cloud rise apparently was neglected.

In looking over the overpressure versus distance number you quoted to me I find they are very conservative relative to the M Problem which we here consider to give answers agreeing with experimental data and are accepted by Porzel of Armour Research Foundation. Liedtke, I believe, used results of Courant's (NYU) work.

As I mentioned before, I believe the data obtained by Evans Signal Laboratory ought to be used to delineate the calculations. The work involved in the computations outlined above is not large and can be done by a number of groups as I indicated before.

May I also ask that if you wish me to review any work that the assumptions, model, and source of the material used in the computations be quoted. Unfortunately in AFSWP-1100 and particularly TM-23-200 this has not been done adequately and hence it is difficult to assess the quality of the predictions.

jc

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LOS ALAMOS SCIENTIFIC LABORATORY
UNIVERSITY OF CALIFORNIA
LOS ALAMOS, NEW MEXICO

OFFICE MEMORANDUM

TO : Distribution

DATE: May 27, 1958

FROM : George Bell

SUBJECT: COMPARISON OF WORLDWIDE HAZARDS DUE TO C^{14}, AND FISSION PRODUCTS.

SYMBOL : T-1026

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In T-1009 (rough draft), estimates were made of the amounts of C^{14} produced by detonations of clean weapons. It was indicated that C^{14} may represent the most hazardous radioactivity produced by detonation of a clean weapon and some comparisons were made with Sr^{90} hazard. Attention has recently been focused on such a comparison by Soviet claims that C^{14} production rendered the concept of a clean bomb meaningless (paper by Liapunsky) and by similar statements of Linus Pauling and others.

It is the purpose of this memo to present a more detailed comparison[1] of C^{14} with the fission products and other induced activities, and to note in what sense C^{14} may be taken to be a worldwide hazard comparable to fission products -- even for a standard weapon. Effects of tritium production will also be discussed.

In attempting to compare C^{14} with fission products, one must first note the impossibility of making any simple comparison. Of the longlived fission products, Sr^{90} and Cs^{137} are conventionally regarded as most hazardous. Sr^{90} is believed dangerous, largely in that it may induce leukemia and bone cancer. Cs^{137} and C^{14} appear to be most hazardous in that they can produce genetic damage and lead to the premature death of individuals in subsequent generations. Genetic death seems a very intangible and theoretical thing compared to leukemia but it is presumably just as real. For a second difficulty, C^{14} has a lifetime which is nearly 200 times that of Sr^{90} or Cs^{137}. Thus damage due to C^{14} will extend over several hundreds of generations whereas that due to Sr^{90} and Cs^{137} will be completed within a few generations (although the Cs caused genetic damage will not become completely manifest for much longer). In addition, genetic damage has a unique property in that heavily irradiated survivors of local fallout may, through intermarriage, transmit a hazard in the form of radiation induced mutations to the entire world. Thus to some extent the effect of C^{14} must be compared with the sum total of all genetic damage produced by fission products or by other local fallout.

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[1] In this undertaking I am indebted to E. C. Anderson for pointing out the relatively short residence time of CO^2 in the atmosphere, and to the article by Liapunsky for indicating that one should integrate C^{14} radiation over a very long time to obtain its full effect.

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leukemia such that per r delivered by Sr^{90} to the bones of an individual there is one chance in 10^6 per year that that individual will subsequently develop leukemia because of that r of radiation. This number was suggested by Lewis (Science 125, 965 (1957)) from an analysis of experimental data. It is in general agreement with the casualty calculation of Langham and Anderson which took about 10% of present leukemia cases caused by radiation. It is exactly a factor two less than the number used by Liapunsky. (Liapunsky took 2×10^{-6} which Lewis suggests as the probability for irradiation of both bones and lymphatic system rather than 10^{-6} which Lewis suggested for bones alone.) Assuming that an average individual will live 30 years after receiving an r, we find the probability of death by radiation induced leukemia to be $3 \times 10^{-5}/r$.

Genetic hazard due to radiation has been discussed by Muller (How Radiation Changes the Genetic Constitution -- Bull. Atomic Scientists 11:329) and in the 1956 report by the Committee on Genetic Effects of Atomic Radiation of the National Academy of Sciences and National Research Council. The geneticists point out at great length their lack of definite knowledge as to the effect of radiation on human genetics. However they do make estimates of genetic damage per r delivered to the gonads. As applied to a long term increase in radiation such as for C^{14}, and for a constant population the geneticists estimate that per r delivered to reproductive organs of an average individual (including those above reproductive age) there will be produced: (1) with probability about 2.5×10^{-5} a tangible genetic defect (such as mental defect, epilepsy, etc.) which will show up in first generation children (2) with probability about 2.5×10^{-4} a tangible genetic defect which will show up clearly sometime (3) with probability about 2.5×10^{-3} a mutation which will, statistically speaking, be eventually eliminated from the race by premature death of an individual. It appears at this time impossible to understand the significance of mutations of this sort (3) in terms of human suffering or burden to society. The geneticists state that their estimates (of (3) above in particular) may be in error by a factor 10 either way. Muller appeared rather confident that the probability of a mutation (3) was very likely larger than above.

Suppose now that we take as a genetic death either a mutation producing a tangible genetic defect ((2) above) or a mutation which will eventually be eliminated ((3) above). Comparing these probabilities of genetic death per r with probabilities of leukemia per r, we find that reproductive organs are 8 or 80 times as sensitive to radiation as are bones. It is to be noted that Liapunsky took criterion (2) above.

We are now in a position to compare the genetic casualties produced by C^{14} with the leukemia casualties produced by Sr^{90}. For example if we assume that C^{14} damage includes that produced over the entire C^{14} lifetime and if we assume that each mutation is a legitimate casualty then we find 125 airburst megatons are required to produce the same number of casualties as are produced by Sr^{90} from 2×10^3 megatons of fission products. This low number is arrived at by dividing the C^{14} long term genetic background doubling yield (2×10^6 megatons) by the ratio of C^{14} to Sr^{90} half life (200) times the ratio of genetic to bone sensitivity (80 counting each mutation as a casualty).

It can be argued that it is unrealistic to integrate the C^{14} damage over all time as we have done. Certainly there are some isotopes which have such long half lives (eg., Cl^{36} with half life of 3×10^5 years) that it would seem nonsense to integrate over all time for these. We have assumed a constant population over $\sim 10^4$ years in computing C^{14} casualties. We have further assumed that it will not become possible to prevent or decrease the effect of radiation induced mutations. Because of these uncertainties as to the long term effect of C^{14} we have also estimated the number of mutations which would be produced in the first generation or two. For this purpose we dilute the C^{14} in the small C reservoir and give it a half life of 5 years. The integrated damage for a given yield and such a short-term calculation is less than the above estimated long term damage by a factor 21 (effective half life is less by factor 5600/5, but concentration higher by factor 8/.15; 5600/5 x .15/8 = 21). The results of these calculations are summarized in Table I.

For orientation, we note that each entry of Table I, with our assumptions, corresponds to of the order of 5×10^5 casualties. For example in the case of Sr^{90} the 2×10^3 megatons of fission products would irradiate the world's population (2.5×10^9) with about 6 r apiece (.15 r/year for assumed 40 years). Multiplying the 1.5×10^{10} man r by probability of leukemia per r (3×10^{-5}) leads to about 5×10^5 casualties, or .25 casualties per kiloton. Note that 5×10^5 C^{14} casualties spaced over 200 generations would imply only 2500 casualties per generation or only one induced casualty per $\sim 10^6$ ordinary deaths.

The question should now be raised whether there are other fission products or induced activities which could lead to comparable damage. From the data of T-1009 we see that Co^{60} produced in very poorly chosen weapon components could be a hazard approaching that due to short term C^{14}. It remains to discuss H^3 and Cs^{137} which were noted by Liapunsky.

As regards tritium, analysis of swordtail calculations reveals that for burning of conventional clean devices, one must expect at least 10^{26} tritons left over per megaton, and in some instances two to three times this number. Taking 10^{26}, we produce 5 Mc tritium per megaton. Libby (P.R. $\underline{93}$, 1337 (1954)) estimated that an available world tritium inventory of 1800 grams, produced mostly by Cosmic Rays, leads to a tritium to hydrogen ratio of $\sim 10^{-17}$ in the biosphere. This implies that tritium in the biosphere is on the average in equilibrium with a reservoir of about 10 gm/cm^2 of hydrogen. By this is meant that if one takes 1800 gm of tritium and mixes it with a hydrogen reservoir of ~ 10 gm/cm^2 of earth surface, he finds $H^3/H \sim 10^{-17}$ as observed in animals. This same reservoir should be effective in diluting bomb made tritium. If we assume that gonads have average body composition, then from NBS Handbook 52 we see that about 20 μc of tritium per kg of hydrogen would double the genetic background radiation level. This would be produced by about 2×10^5 megatons. It follows that the tritium genetic damage would be closely comparable to short term C^{14} genetic damage. With our above numbers we actually obtain 5×10^3 megatons for tritium damage equivalent to C^{14} damage from 2.6×10^3 Mt. However these numbers are uncertain enough to be equal for all practical purposes.

TABLE I

Comparison of C^{14} and Sr^{90}

Number of megatons airburst (clean or standard) producing a number of C^{14} genetic casualties equal to the number of leukemia casualties produced by Sr^{90} from 2×10^3 megatons fission. (For comparison, yields are also given for equivalent genetic damage by tritium and Cs^{137}).

	Integrating C^{14} radiation over all time with stable population.	Integrating C^{14} radiation only over first generations.
Counting each inherited mutation which must be eliminated from genetic strain as a genetic casualty.	125 Megatons	2600 Megatons (Cs^{137} 500 Mt fission) (T 5000 Mt fusion)
Counting as genetic casualties only those mutations which will lead to "tangible genetic defects."	1250 Megatons	26,000 Megatons (Cs^{137} 5,000 Mt fission) (T 50,000 Mt fusion)

DOE b(3)

[redacted]

Length - 40" - 50"

TYPE II:

DOE b(3)

[redacted]

DOE b(3)

[redacted]

Length - 40" - 50"

TYPE III:

DOE b(3)

[redacted] This type can probably be made with the following very approximate characteristics assuming that the basic design is feasible.

DOE b(3)

[redacted]

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Total Yield: Weight:

[redacted]

DOE b(3)

Length - 50" - 60"

II. Possible Time Scales for the Various Types

This section gives a possible set of self consistent time scales for developing the three types of devices listed in Section I. In order to make up this schedule, we have made the following assumptions.

1. [redacted] DOE b(3)
2. The "breaks" will be with us at virtually every step of the development.
3. There will be no net increase in weapons R & D effort, but the program will be given a high priority within the effort available. Some other programs now tentatively scheduled for Phase III will have to be dropped.
4. Each design problem can be solved in regular sequence by continuous extrapolation as the development proceeds, i.e., no new R & D "break-throughs" are required.

The following table gives a possible weapons test program for the development of the clean tactical weapons:

	Device Test	Weapon Prototype Test
Hardtack (Pacific, 1958)	Type I Type II	
Nevada, 1959	Type II [redacted] Type III	Type I Type II (?) DOE b(3)
1960	Type III	Type III (?)

The following table gives a possible joint UCRL-Sandia Weaponization Program. Other weapons are also included to indicate what other programs can be carried on at the same time as a serious program of tactical clean weapons development. The dates given are the fiscal years in which the indicated weaponization program would begin. These dates are, of course,

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very tentative and are intended primarily as examples of what might be done, since they depend on all of the speculations and estimates above, as well as on DMA-DOD estimates of relative importance and determination of priorities.

FY 1958 [redacted]

FY 1959

DOE - b(3)

FY 1960 Nike Zeus, Polaris

FY 1961 Clean Type III, ?

DOE b(3)

Assuming that all of the above time schedules can and will be met, the following is then a list of the dates at which the various types might enter the stockpile:

Type I - CY 1960

Type II - CY 1961

Type III - CY 1963

III. The Meaning and Importance of Cleanliness in Tactical Atomic Bombs

The reason for developing and producing clean tactical bombs is to provide the armed forces with nuclear weapons of low and intermediate yield which can be used in situations where, because of radioactive contamination, a tactical atomic weapon of the present 100% fission type cannot be used. Perhaps the most important and easily described situation of this type is that in which it is desired to remove or destroy, by means of a ground burst, a hard target, such as a deeply dug in enemy or an airstrip, in friendly territory or in close proximity to our troops. As indicated by an overall analysis of the recent Army "Sagebrush" exercise, (which involved, among others, ground bursts on airfields), such applications are very dangerous, or, more probably, generally impossible using the present day atomic weapons. In the case of high air bursts, in which the fireball is well off the ground, the situation is less bad in the present case of pure fission bombs, since the radioactivity is generally spread out over a very large area and a very large number of tactical size bombs can be used without approaching the world wide "Sunshine Limit." However, even in this case, there is still the problem of possible serious localized "rain out" which problem would, of course, be greatly alleviated or completely removed by the use of clean bombs.

DOE b(3)

None of the bombs listed in Section I are, of course, absolutely clean but all of them represent very large improvements in this respect

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over the present stockpile. [redacted] DOE b(3)

It may be noted from the tables that, for most of the cases considered, the area of lethal radiation is less than the area of other lethal effects. [redacted] DOE b(3)

All distances given in the tables are for unprotected personnel in the open. The ranges and areas of the various effects are either taken from "Capabilities of Atomic Weapons," AFSWP, Rev. 1 June 1955, or have been calculated from basic data given there. All of the numbers, of course, are very rough estimates, both because they are for one particular set of field conditions (i.e., an average wind of 15 knots) and because some of the necessary important input data are not accurately known. [redacted] DOE b(3) The detailed distribution of such intense radiation fields have not been measured and there is in fact some doubt as to their existence). The various assumptions made in preparing the table, and the uncertainties and limitations inherent in such an oversimplified treatment of the problem are given immediately following the tables.

TABLE I - Area in Square Miles for Various Effects

Fission Yield & Effect		Total Yield
		[redacted] DOE b(3)
100%	400 R 50 R	[redacted]
[redacted] DOE b(3)	400 R 50 R	[redacted]
[redacted]	400 R 50 R	[redacted]
[redacted]	400 R 50 R	[redacted] DOE b(3)
Direct Casulties Produced by Blast		[redacted]

For friendly troops, I would think distance is the important parameter not area. — [illegible]

The assumptions and limitations of the table are given below:

1. Winds - The handbook gives the fallout range parameters for wind pattern having an average velocity of 15 knots. The range given is the distance downwind (as determined by the winds at around 10,000') at which a given dosage would be found. The crosswind range is about $\frac{1}{4}$ of the downwind range for large dosages, and the upwind range is, of course, smaller still. For winds differing from those assumed here, the fallout situation will differ also. In this brief analysis it has not been possible to include these cases.

2. Determination of Intensity - It was assumed that if a pure fission bomb gives a dose of R at a point P, then a clean bomb of the same yield fired under the same conditions having a ratio f of fission to total yield will give fR at point P. This assumption should be precise except for the added effects of induced activity which is discussed below.

[redacted] DOE b(3) In fact, there is some doubt that such very high dosages exist at all, except perhaps in very localized hot spots, in which case the "range" and "area" of lethal fallout may be much smaller than indicated.

3. Time Spent in Radiation Field - All radiation doses have been calculated for the case where an unprotected person is at the indicated range from the time at which fallout begins until five hours after shot time. For other time intervals and for the higher dosages, the dosage rate may be very roughly estimated as follows:

   If the time spent in the fallout zone is from time-of-fallout to time-of-fallout plus one half hour, then multiply dose by about $\frac{1}{2}$.

   If the time spent in the fallout zone is from one hour after shot to ten hours after shot, then multiply dose by about 1/3.

   If time spent in fallout zone is from time of fallout to one month or more, then multiply dose by about $1\frac{1}{2}$.

4. Radiation Protection Possibilities - According to the handbook quoted above (pg. 188), very simple precautions can greatly reduce the fallout radiation dosage received. [redacted] DOE b(3) It would

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6. Weight Penalty - [redacted]

?
DOE b(3)

We believe that the above rough discussion of the meaning and evaluation of cleanliness is sufficient for use as a guide to the development of clean tactical bombs. However, we must point out that much better experimental data is needed for input to further calculations, and that many more cases (other wind conditions, burst conditions, etc.) must be calculated in order to get a really good picture of the value and increased usefulness of clean tactical bombs.

[redacted]

[illegible]
DOE b(3)

Very truly yours,

Original signed by
Herbert F. York

HERBERT F. YORK
Director
UCRL - Livermore

HFY:jbr

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